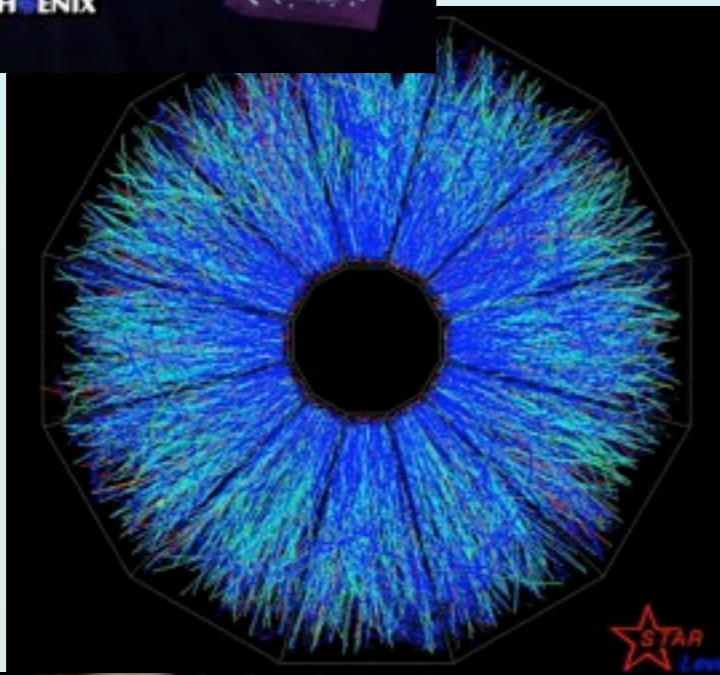
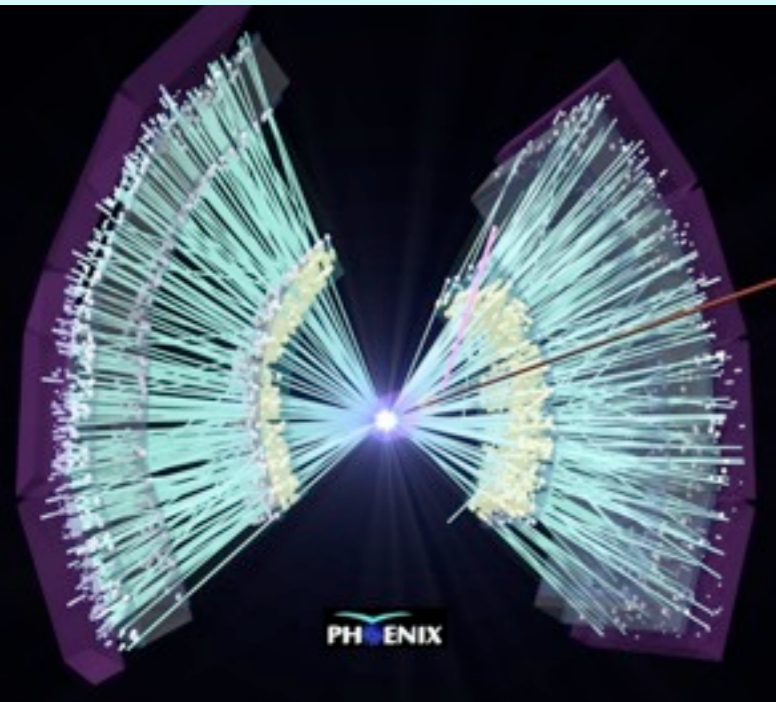
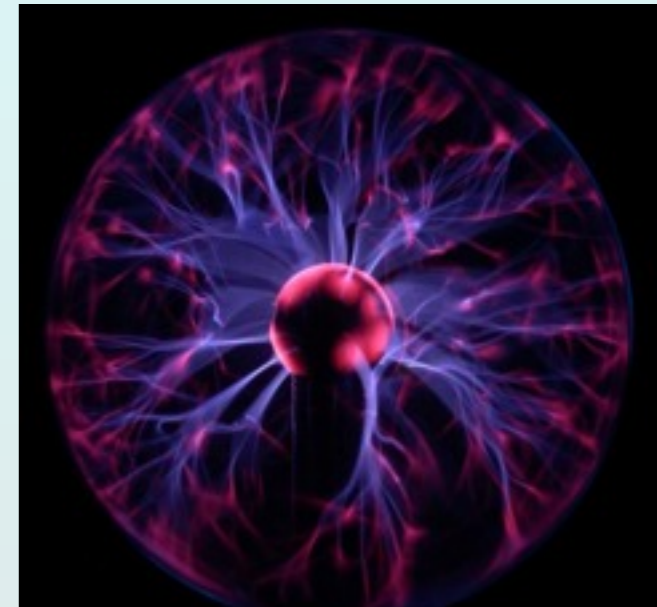


Surprises at RHIC: The Perfect Liquid and Beyond



Barbara Jacak
Stony Brook
University

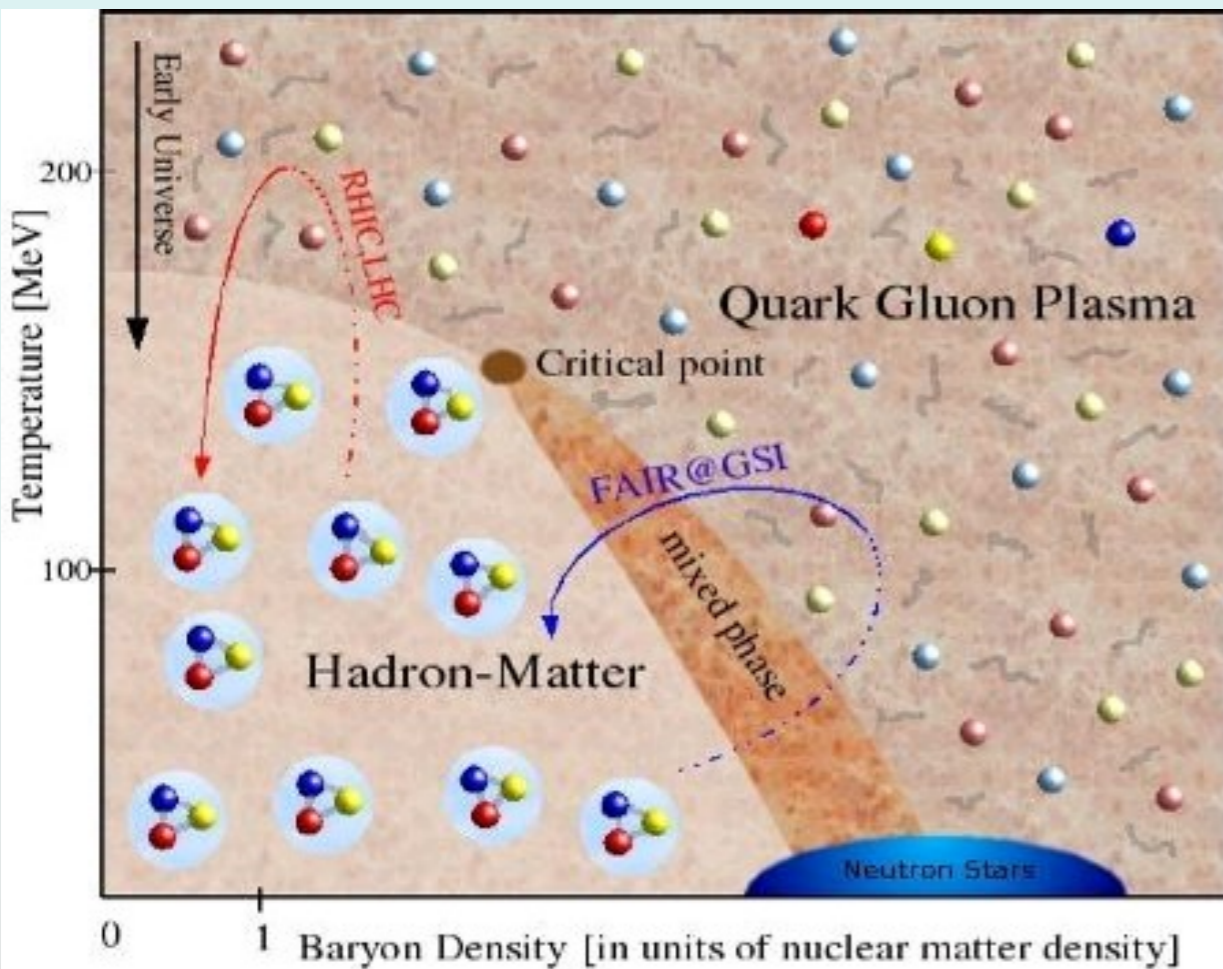
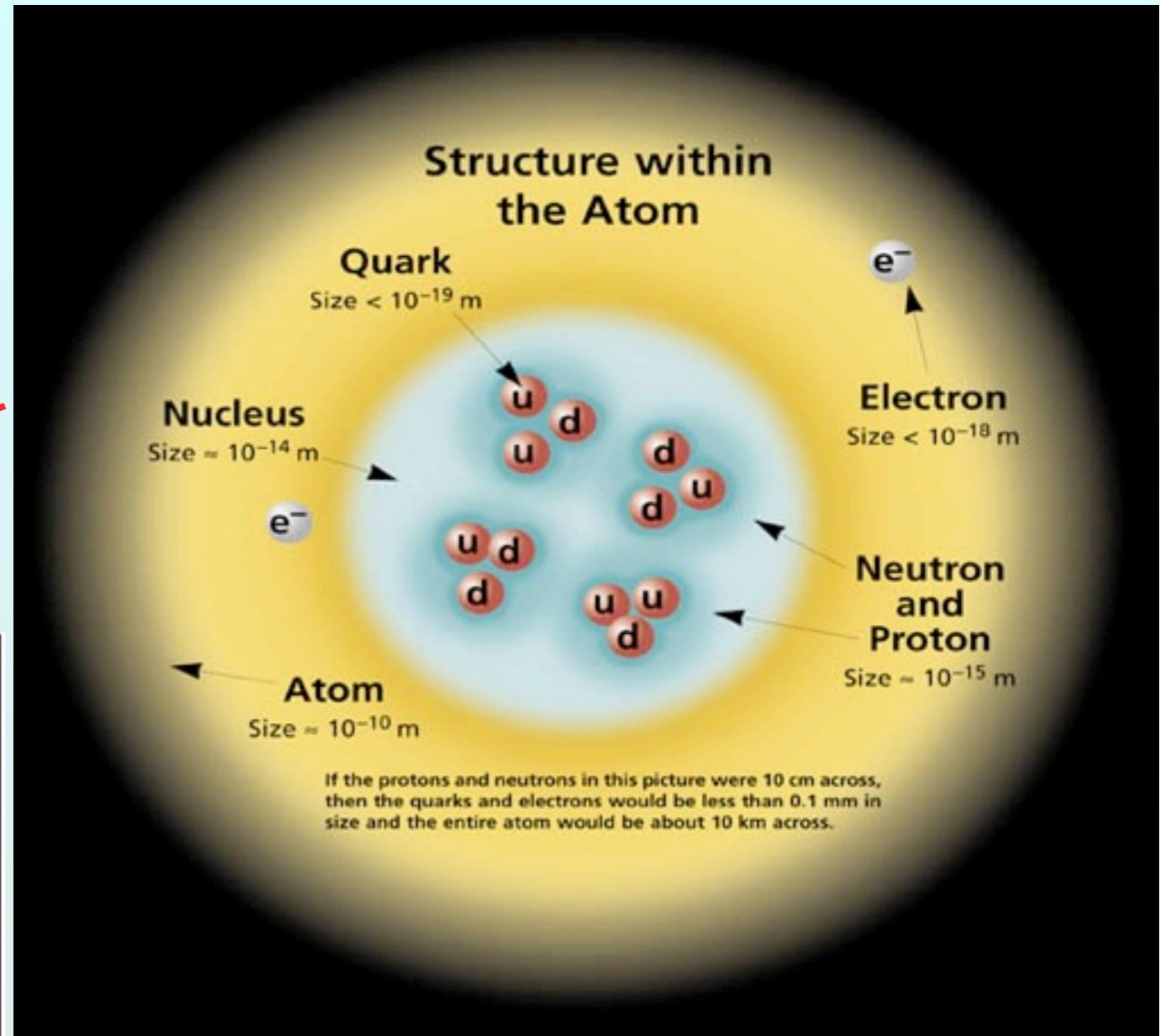
February 15, 2009



Create the hottest matter on earth

Heat to $T > 10^{12}$ K

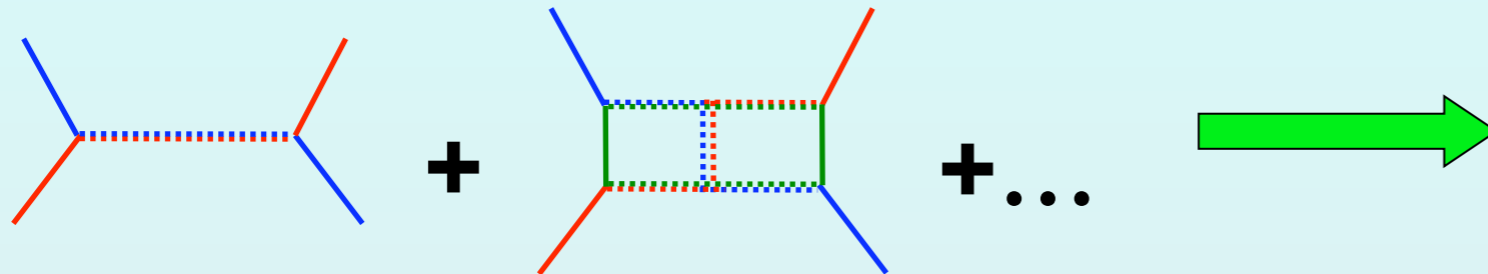
last seen: $\sim 1 \mu$ second
after the Big Bang!



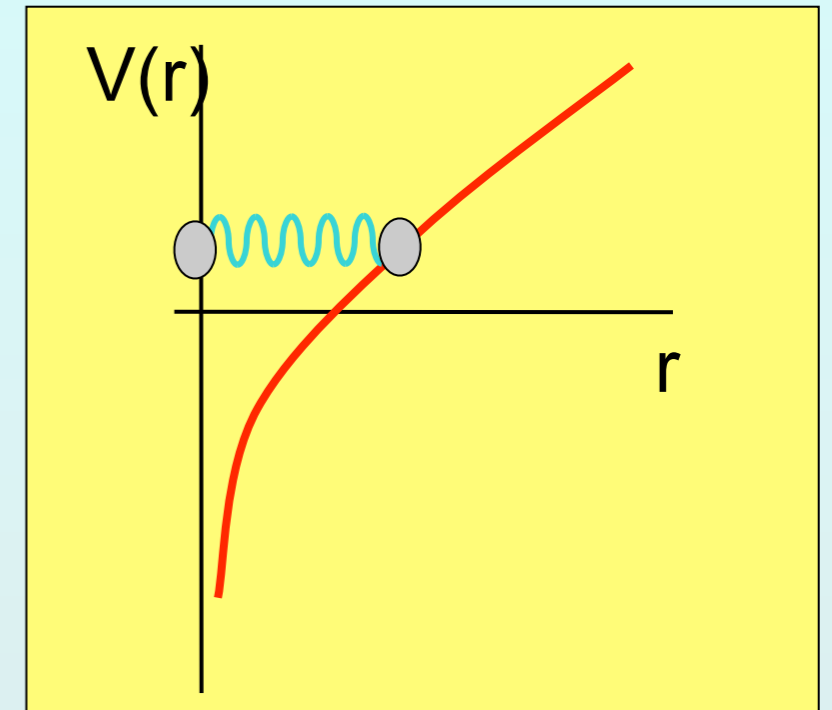
What is it? How does it
work?????

The theory of quarks & gluons: Quantum Chromodynamics

- Quarks interact by gluon exchange
gluons interact with each other too

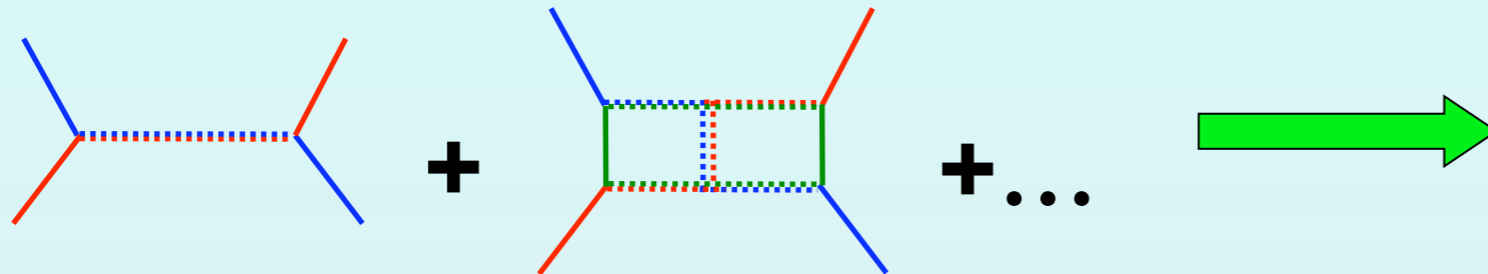


- Curious property at large distance
“confinement” inside particles
Nobody has ever seen a free quark
- Calculating is a challenge
Use a lattice of gluons & quarks



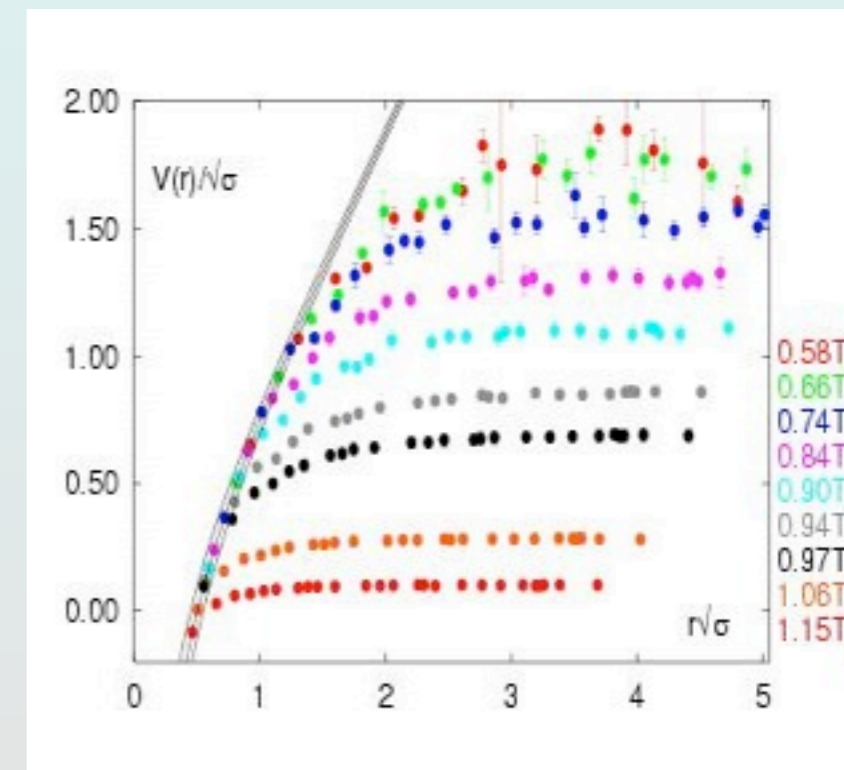
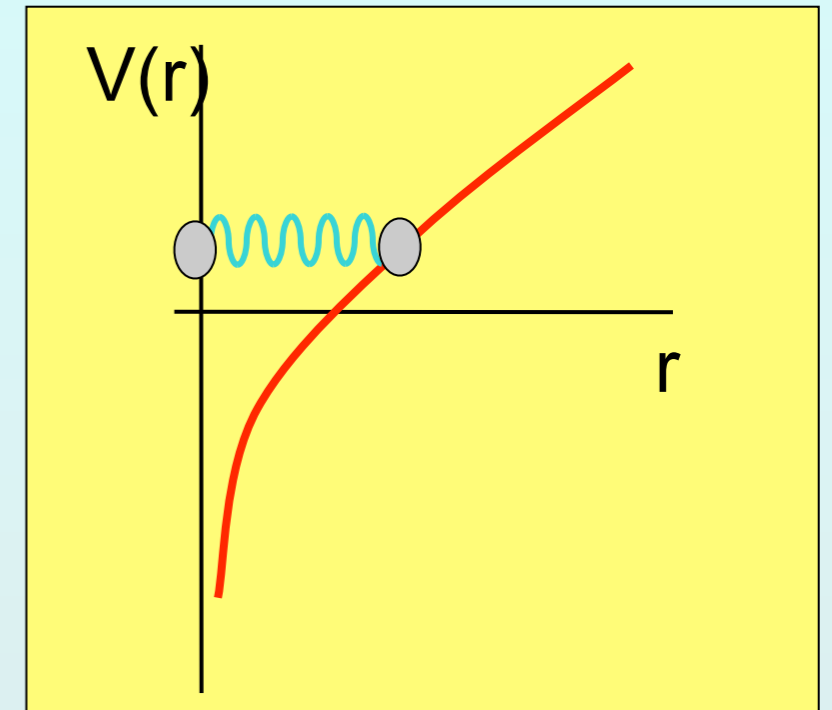
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- Calculating is a challenge
Use a lattice of gluons & quarks

***At high temperature/density the force
is “screened” & gets weaker***



Heater: Relativistic Heavy Ion Collider

RHIC collides two gold beams at 99.99% speed of light



Brookhaven National Lab

Heater: Relativistic Heavy Ion Collider

RHIC collides two gold beams at 99.99% speed of light



AAAS 2009

Heater: Relativistic Heavy Ion Collider

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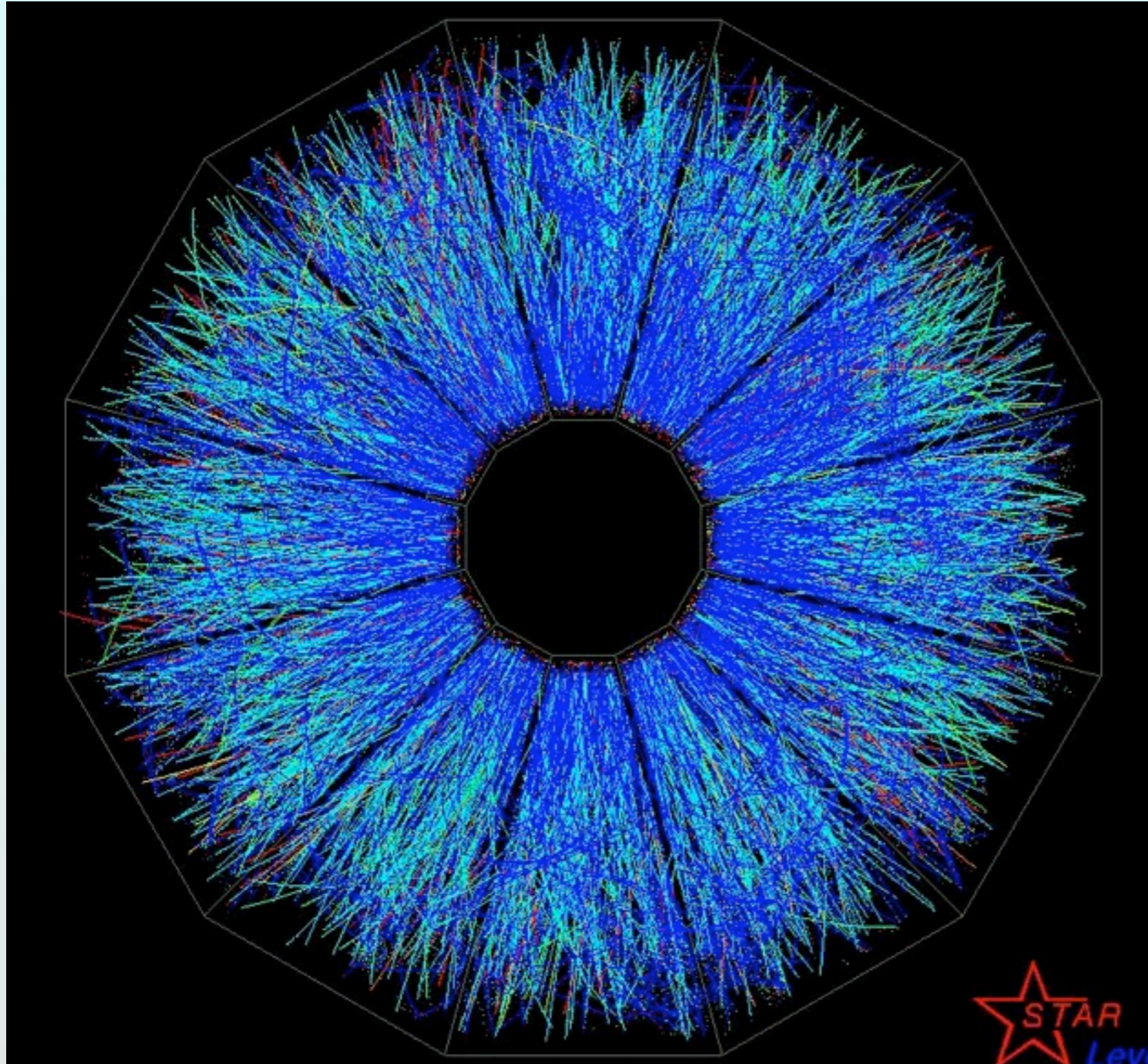


Hundreds of thousands of detector channels!

AAAS 2009

Heater: Relativistic Heavy Ion Collider

RHIC collides two gold beams at 99.99% speed of light

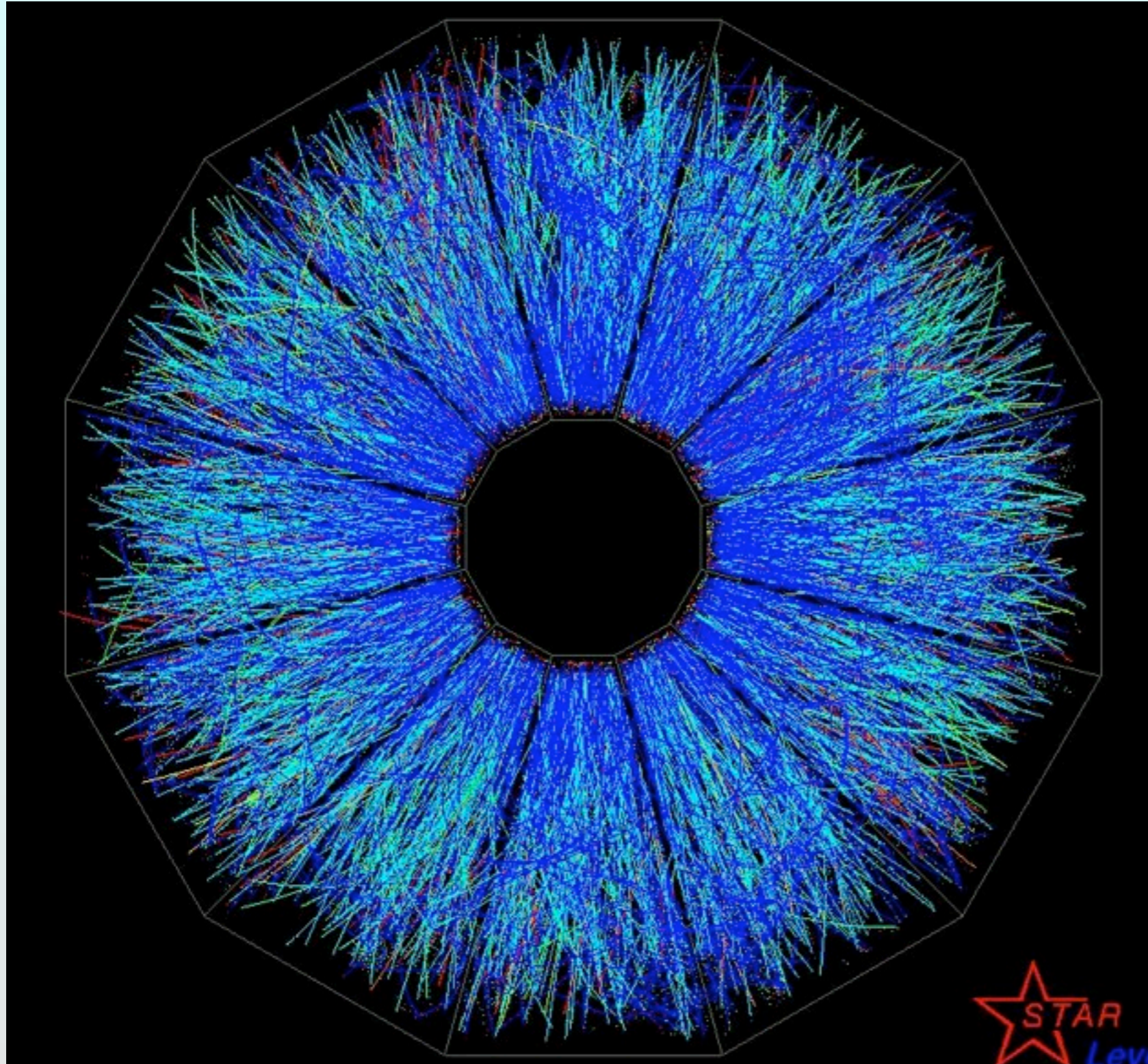


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Heater: Relativistic Heavy Ion Collider

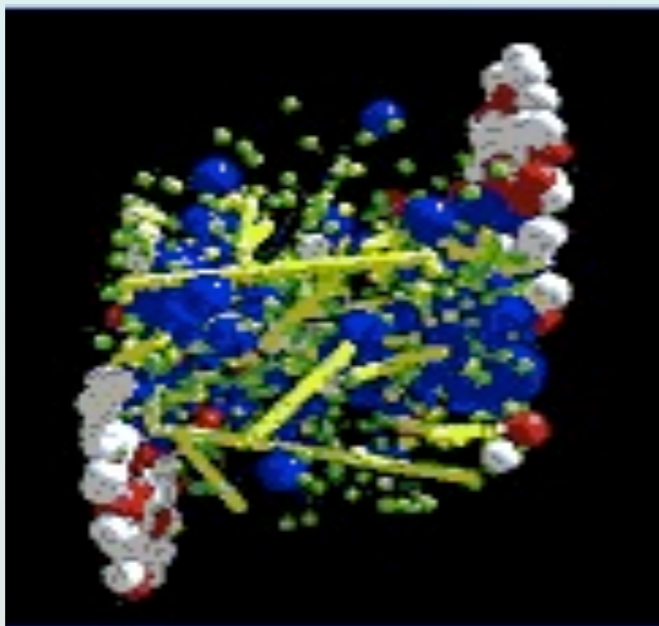
RHIC collides two gold beams at 99.99% speed of light



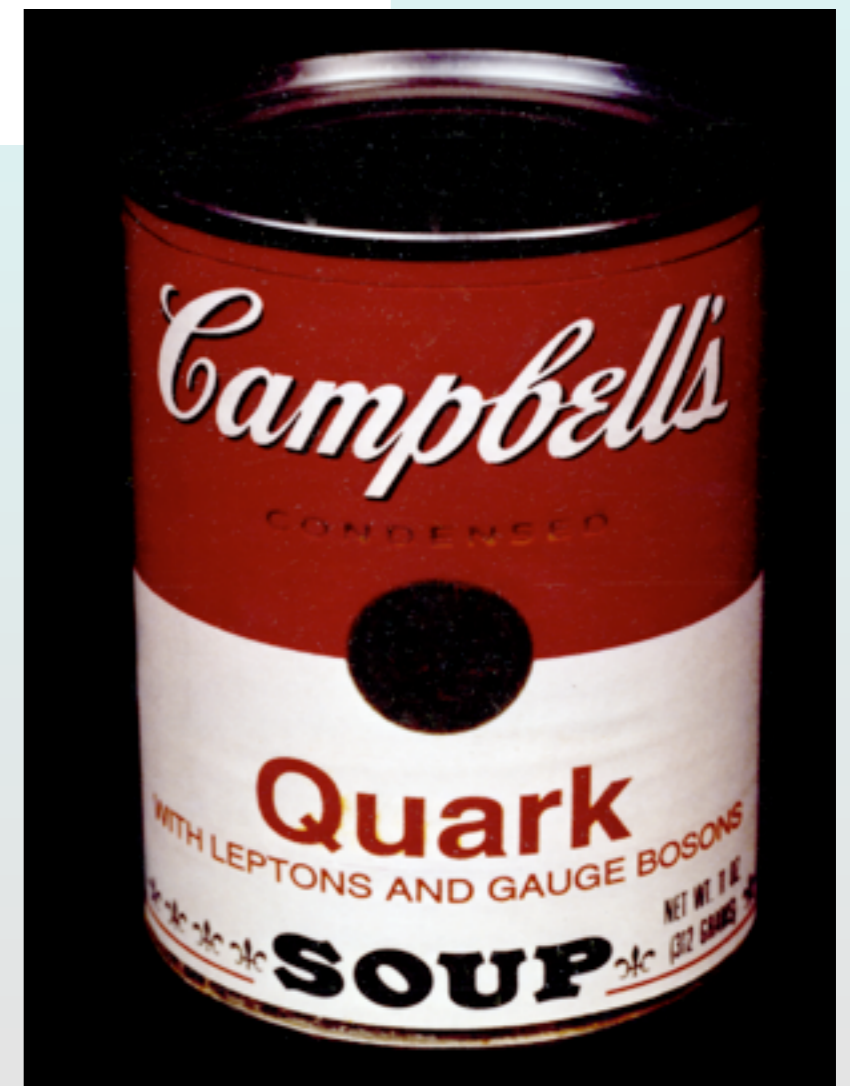
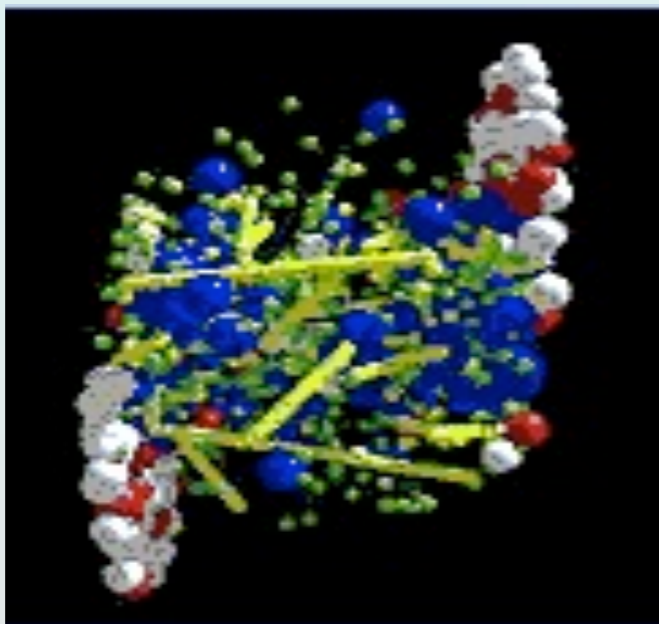
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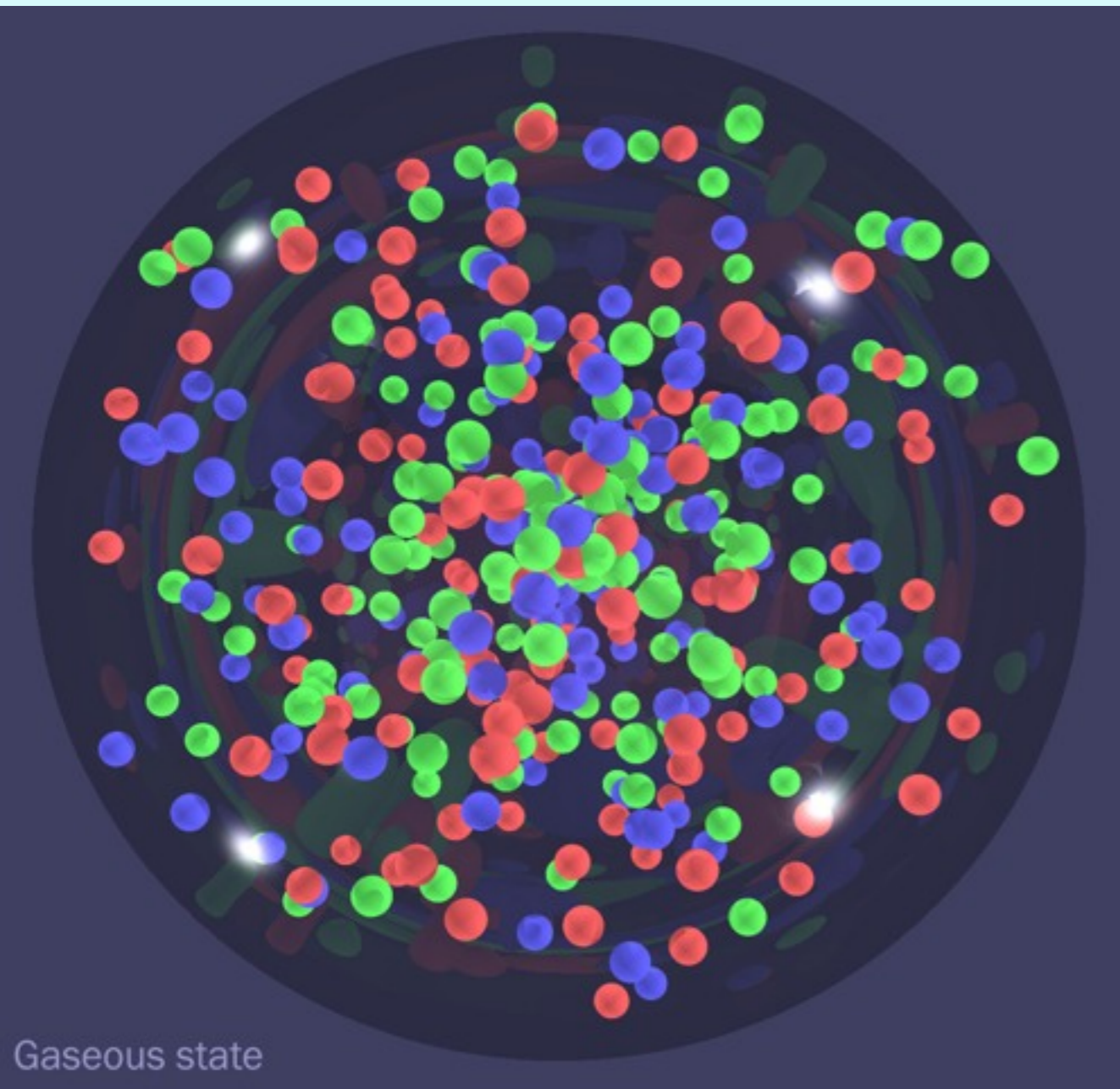
We looked, and we found...



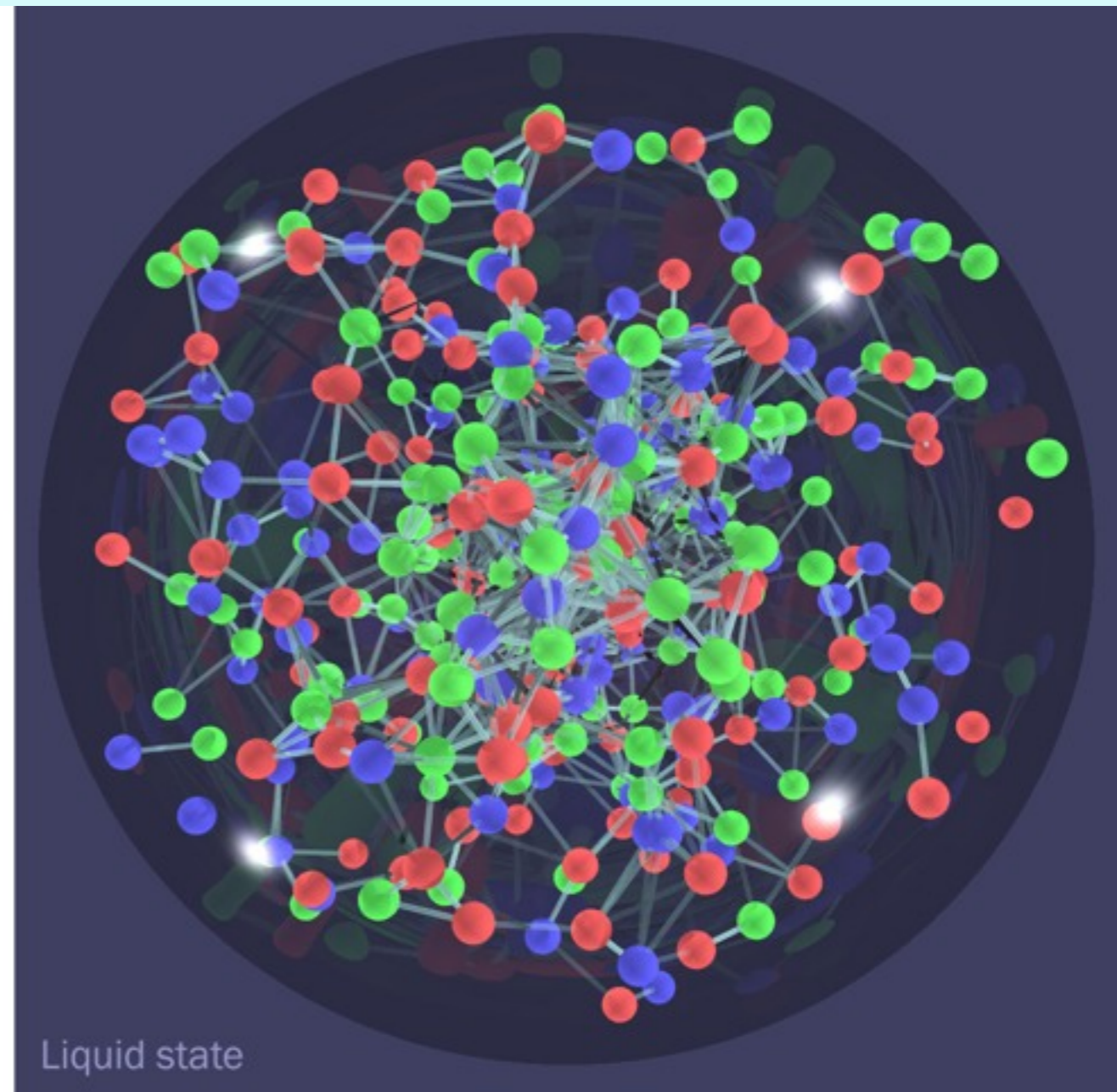
We looked, and we found...



“soup” is more correct than you’d think...

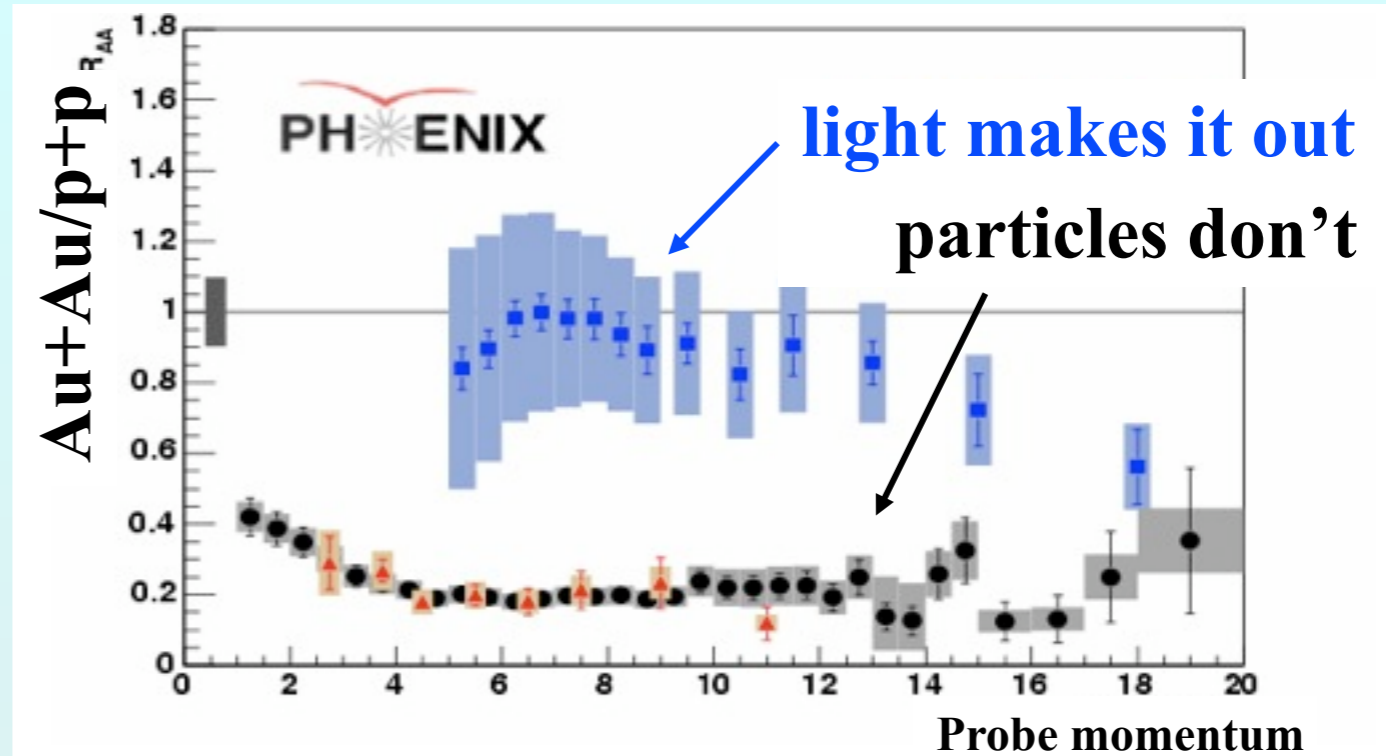
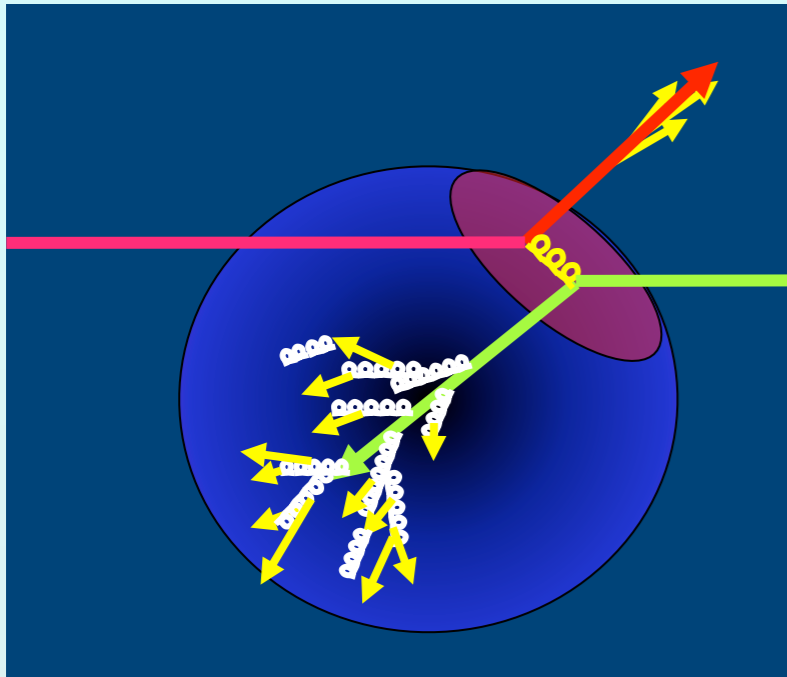


Gas: particles only know about each other when they bump

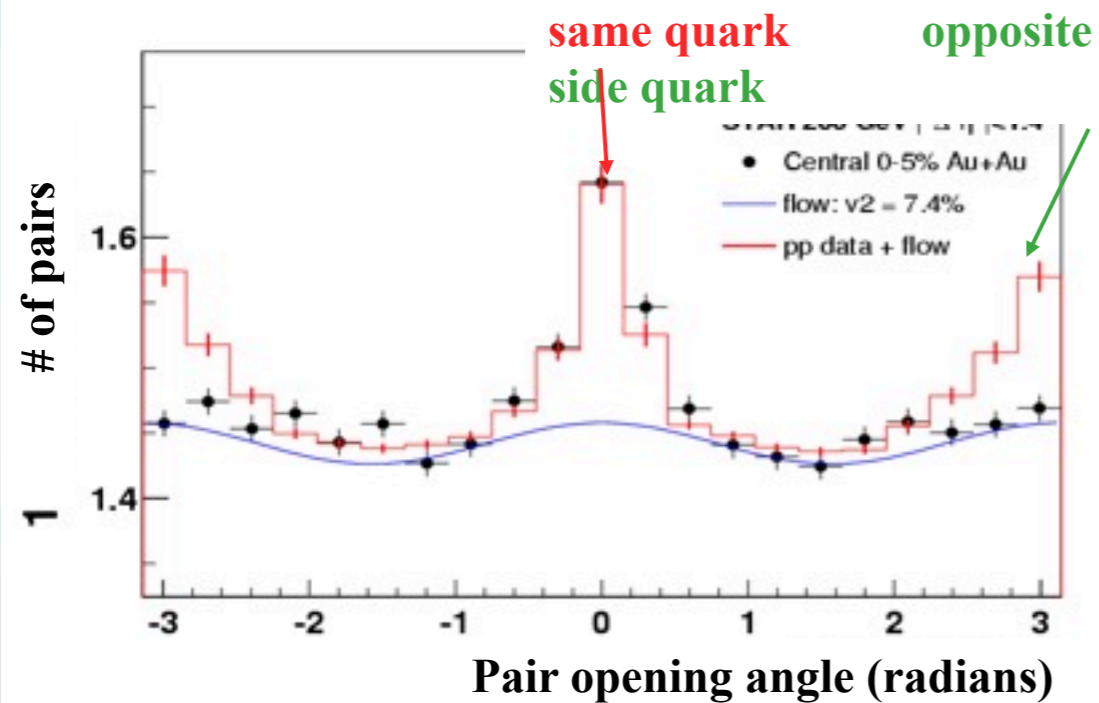
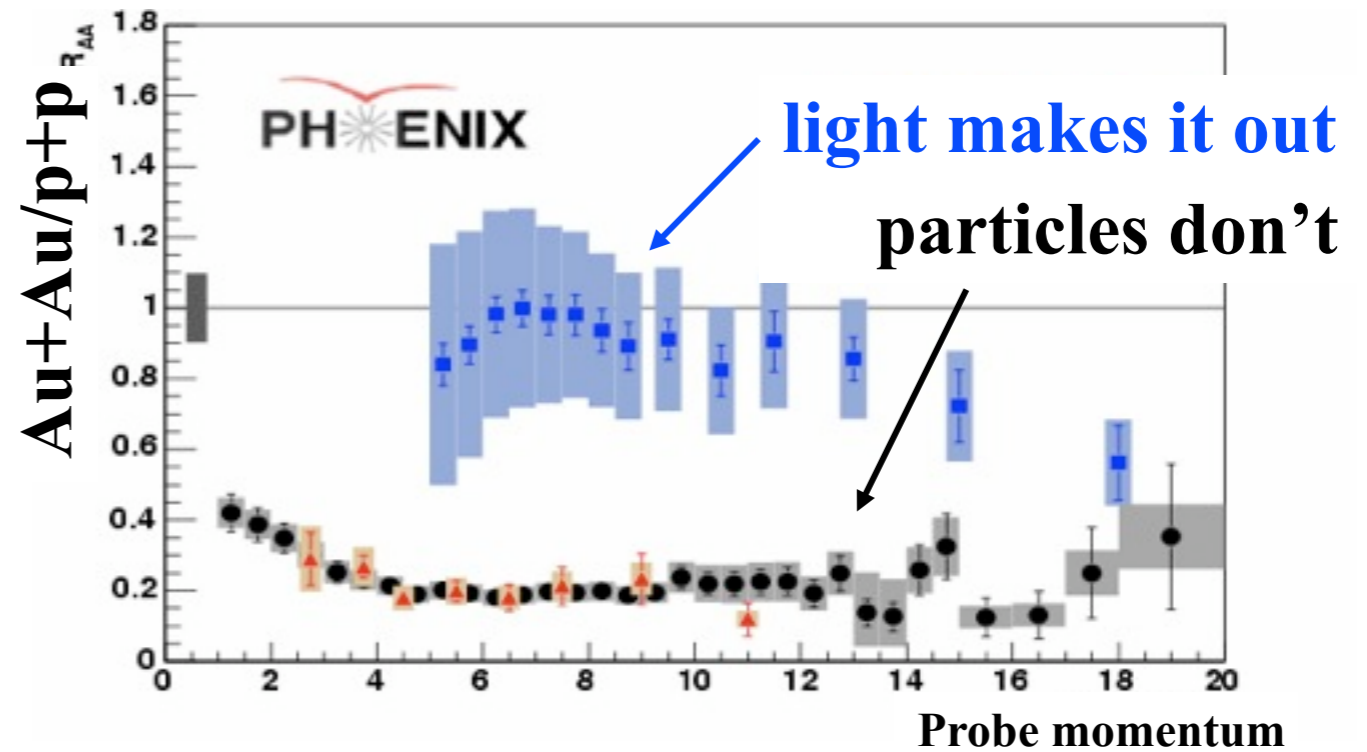
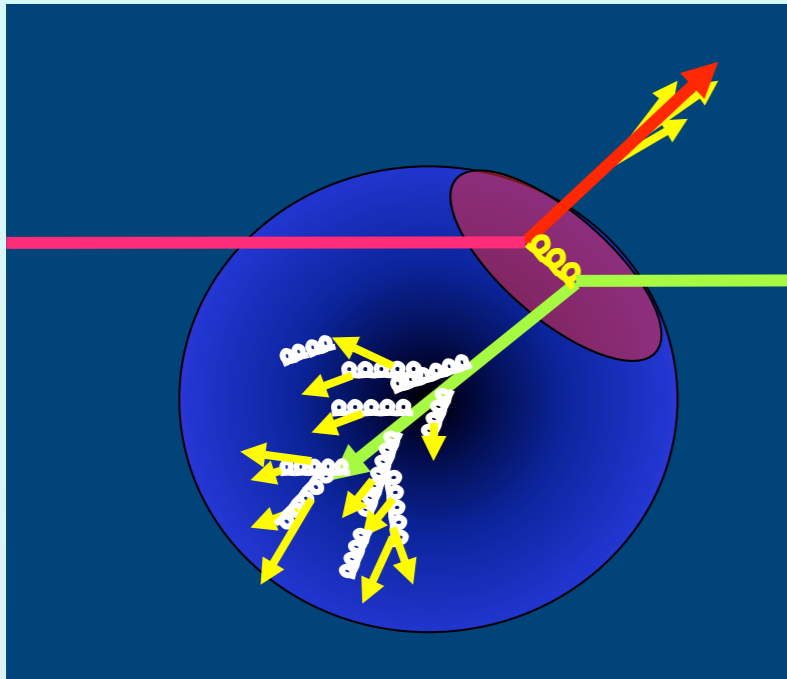


Liquid: particles exert forces on one another all the time, flows in a coordinated fashion

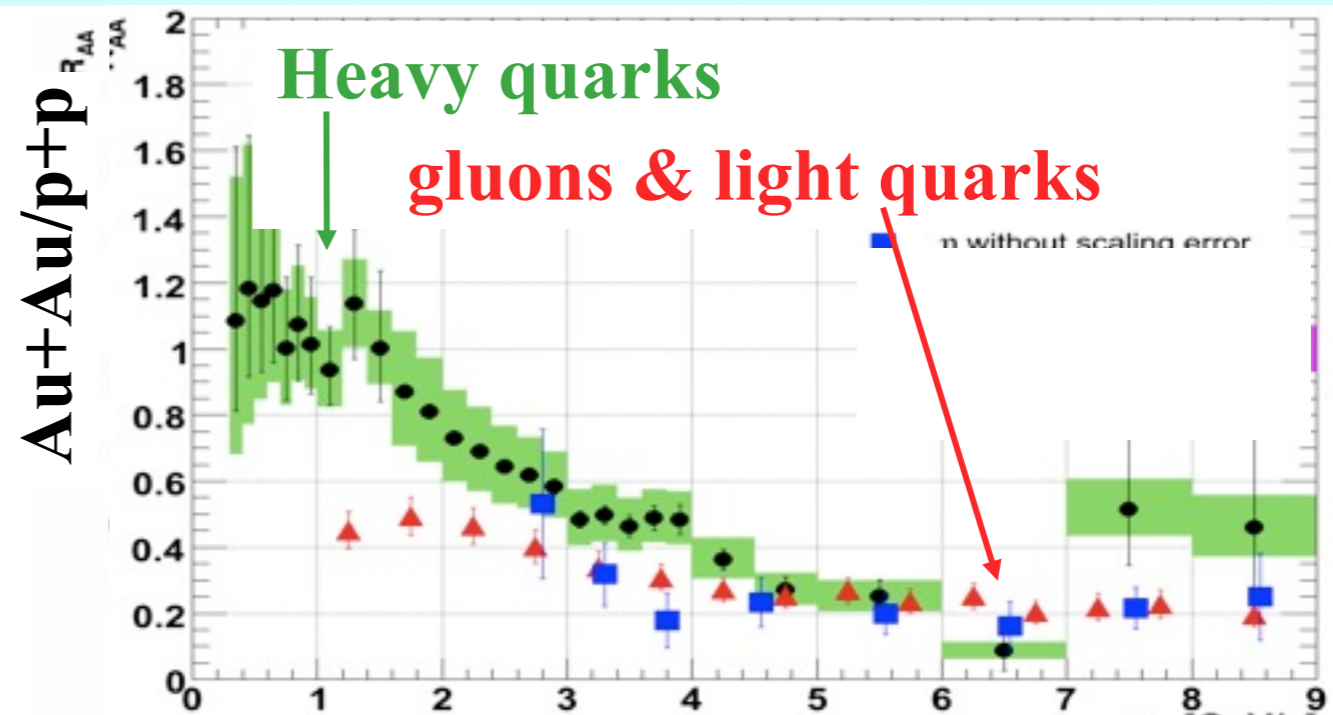
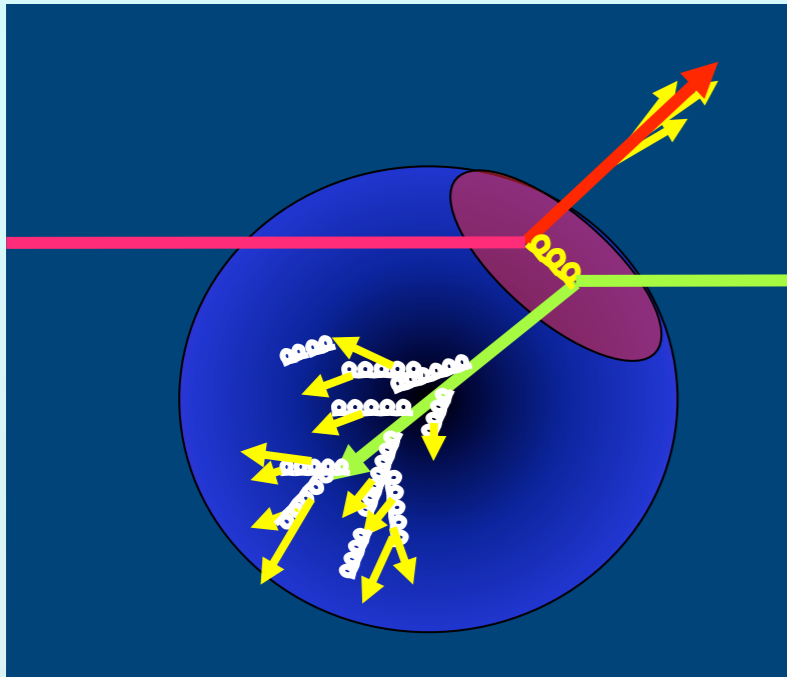
Surprise: nothing can get through!



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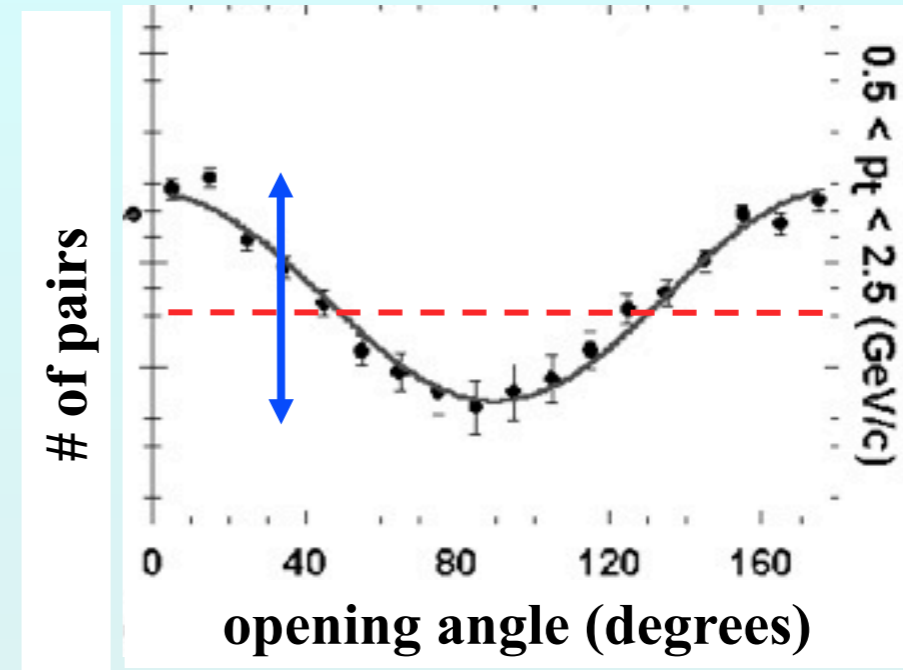
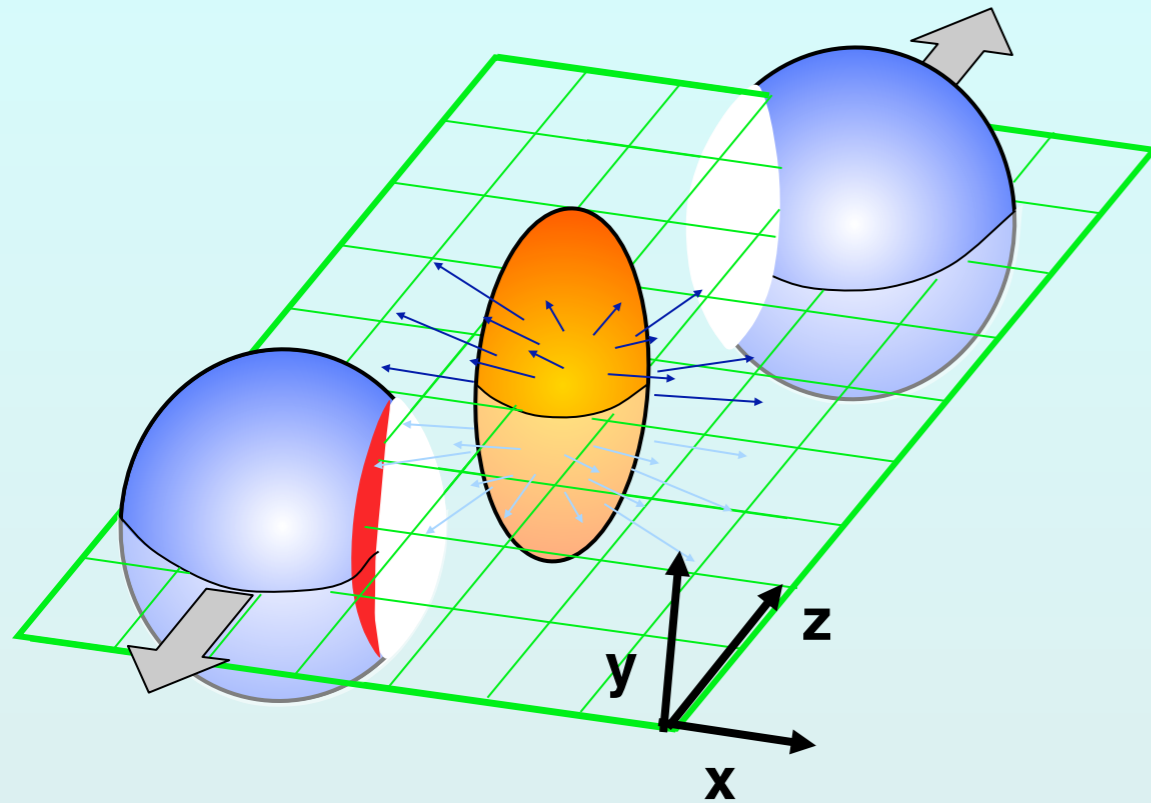
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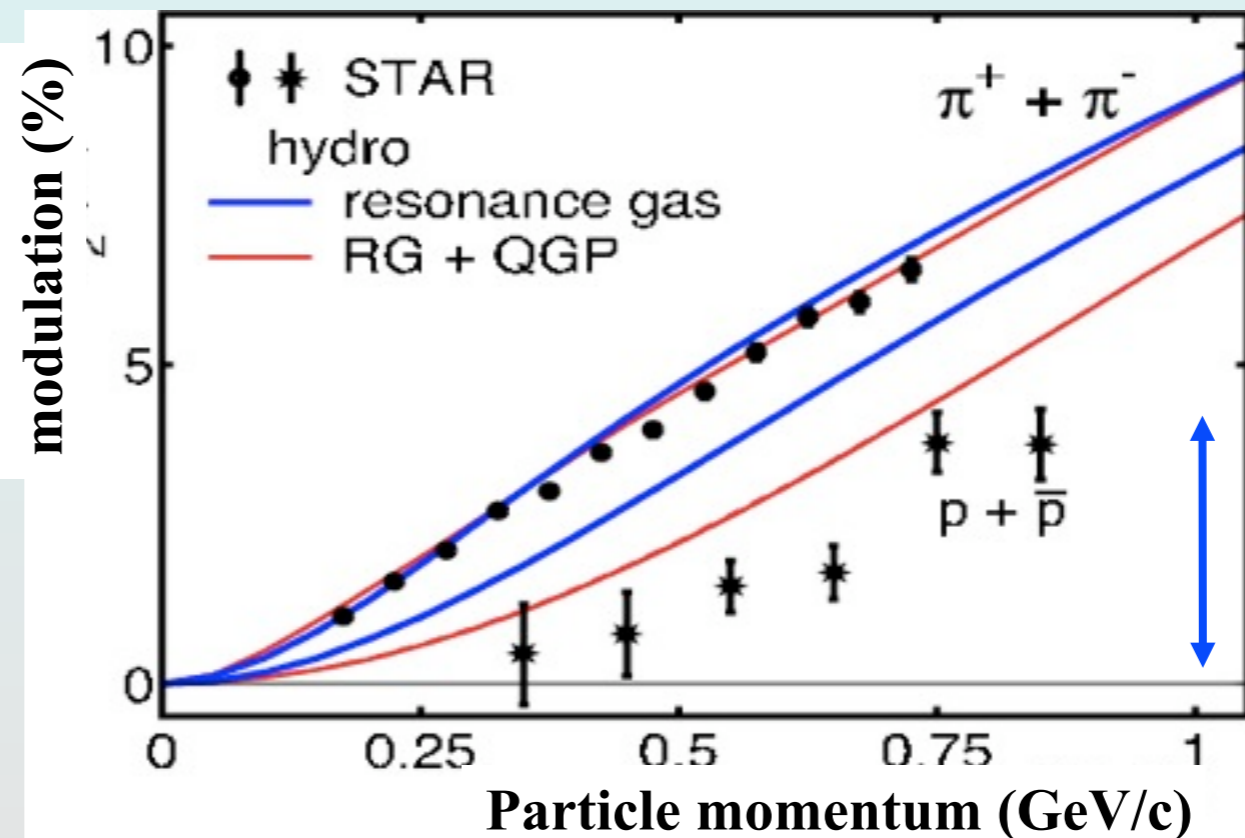
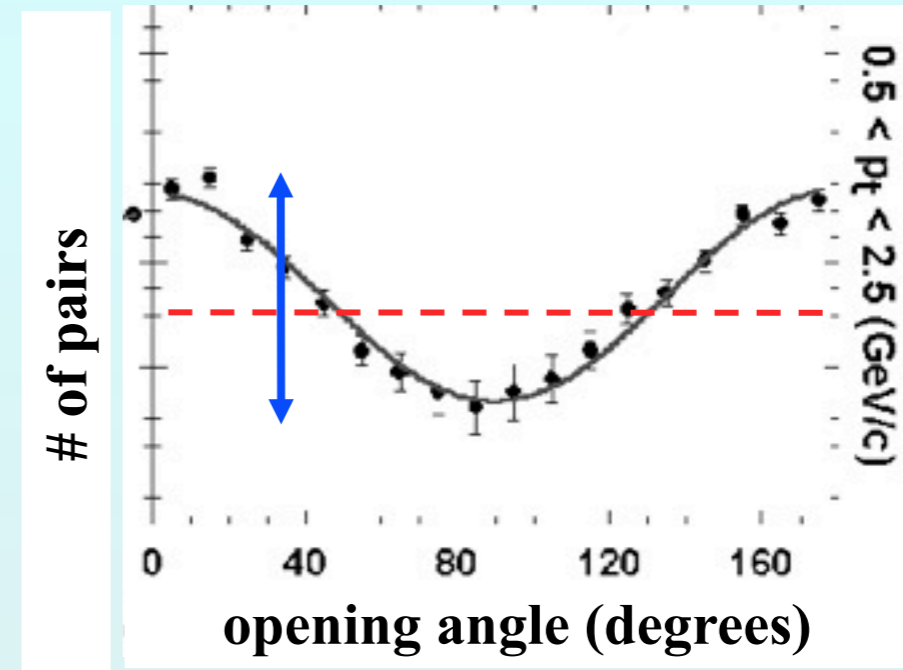
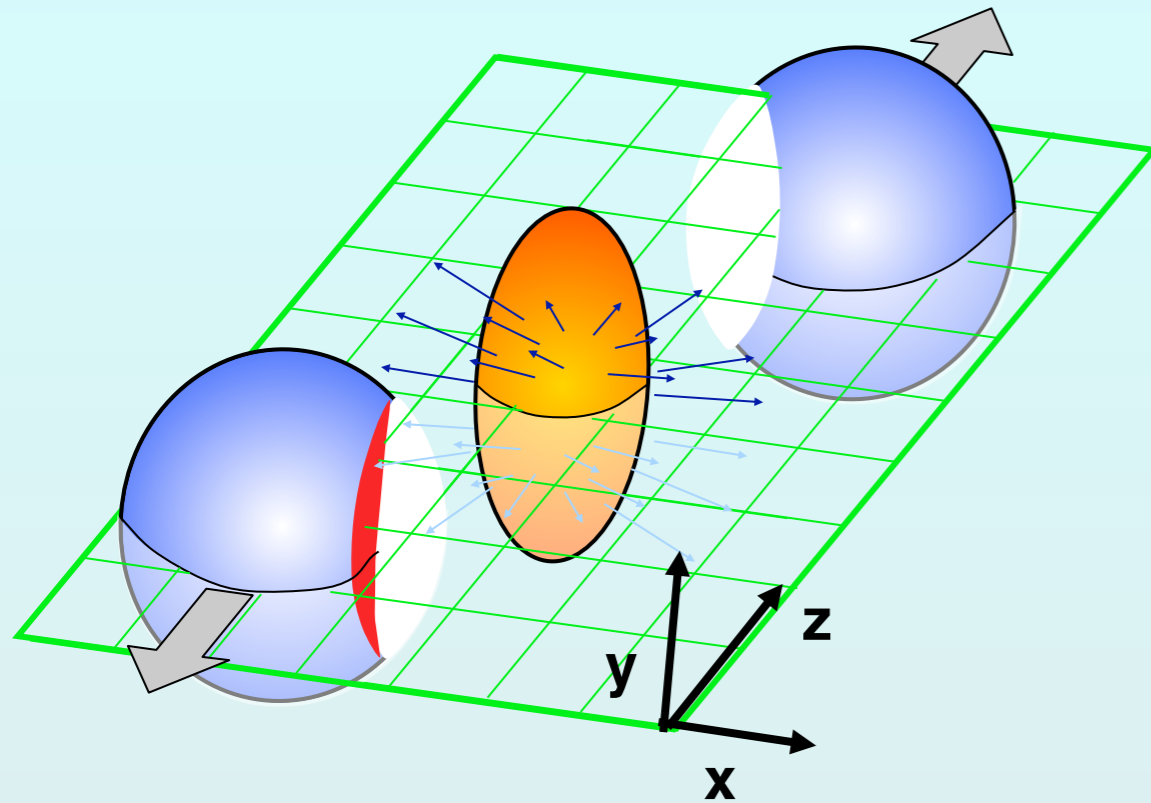
Surprise: heavy charm quarks don't make it through, either!



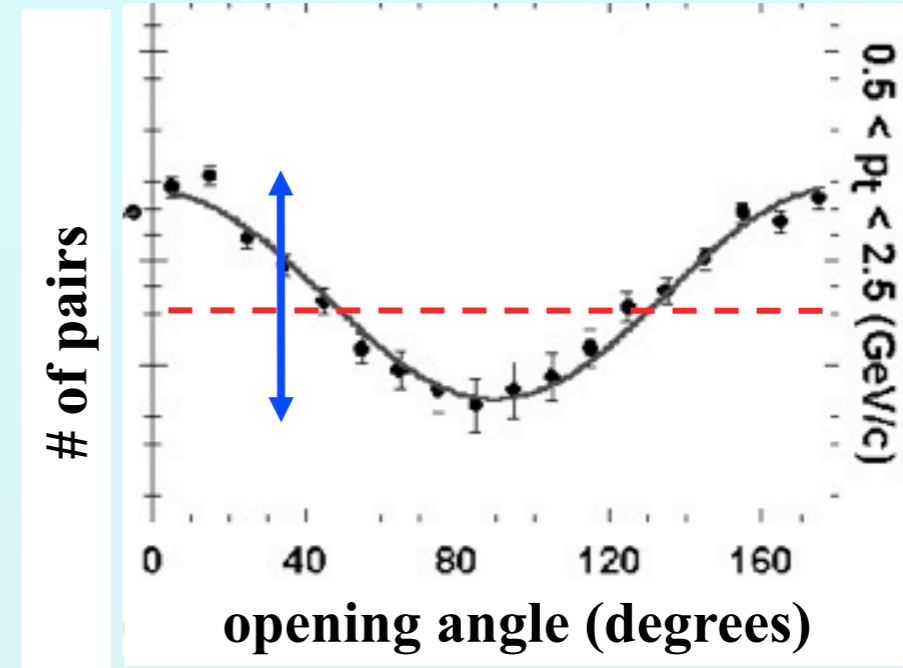
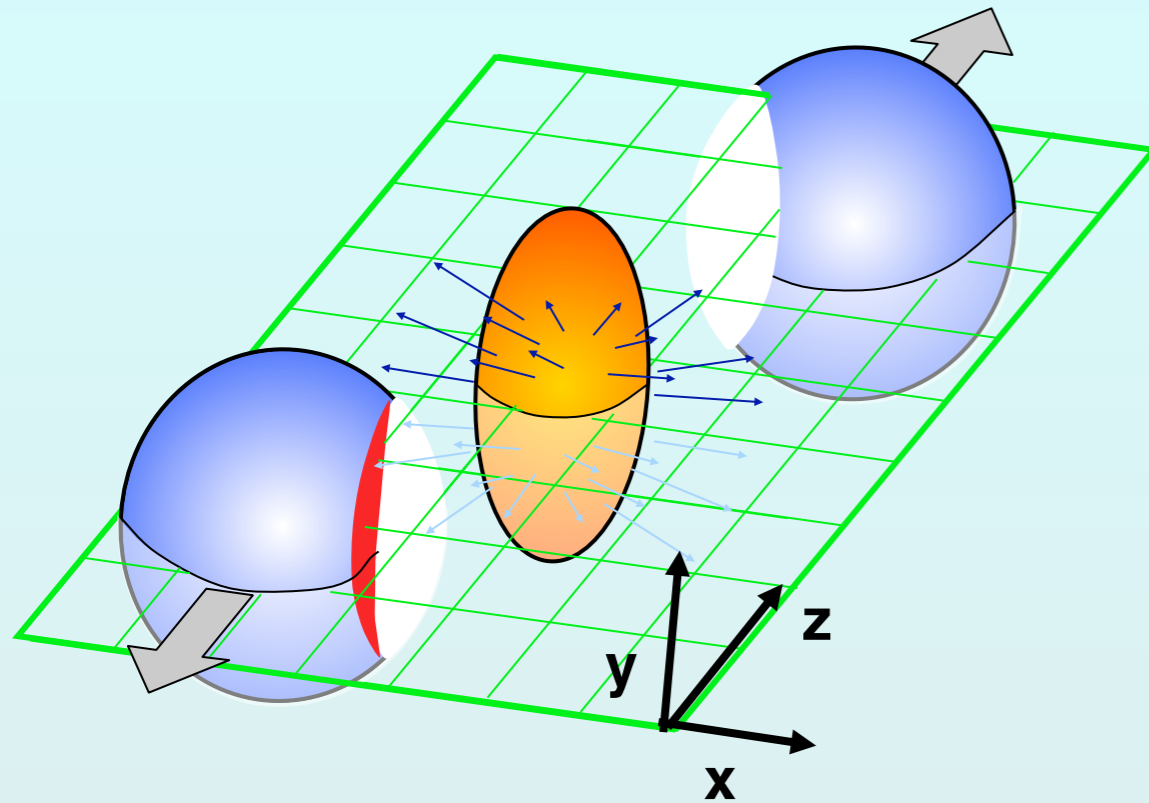
Surprise: the matter flows like a liquid!



Surprise: the matter flows like a liquid!



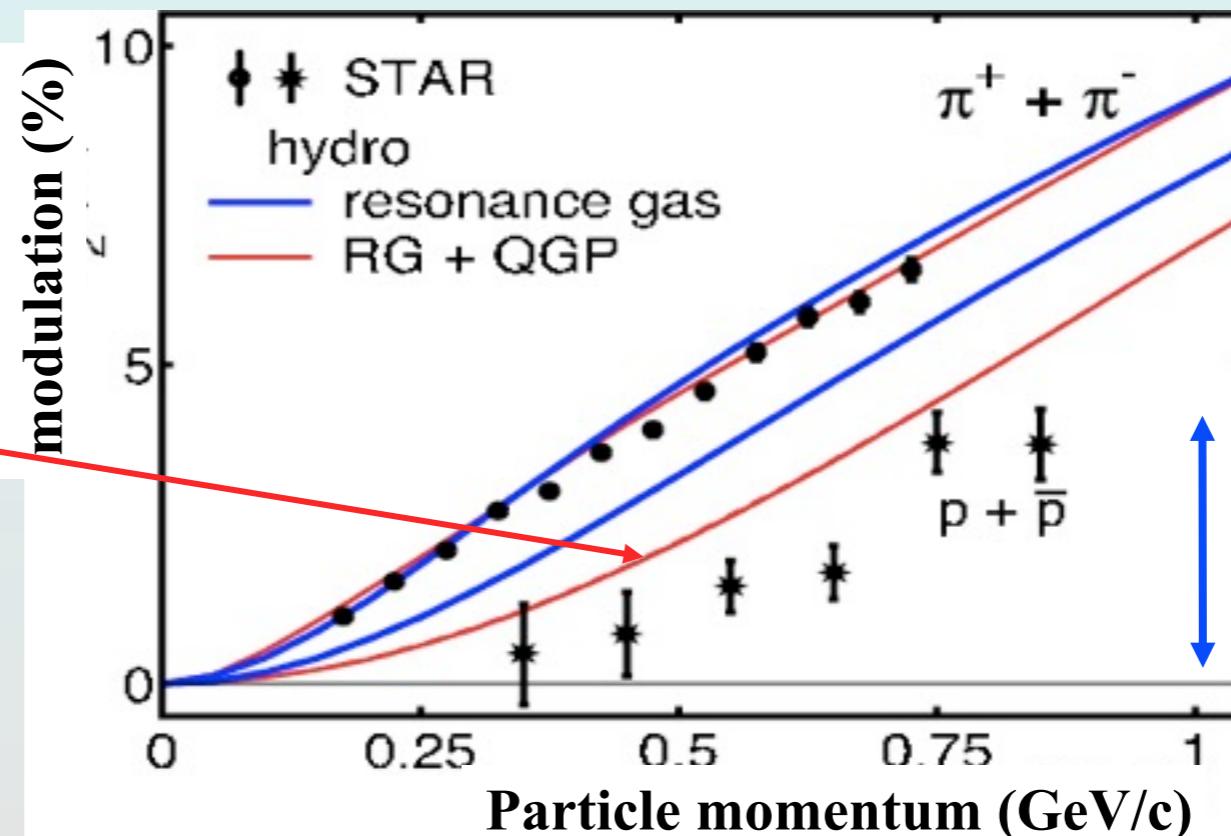
Surprise: the matter flows like a liquid!



Use data to constrain hydrodynamic* model:

It works IF:
include a plasma
with tiny viscosity

* *Hydrodynamics is used to model many kinds of fluids*



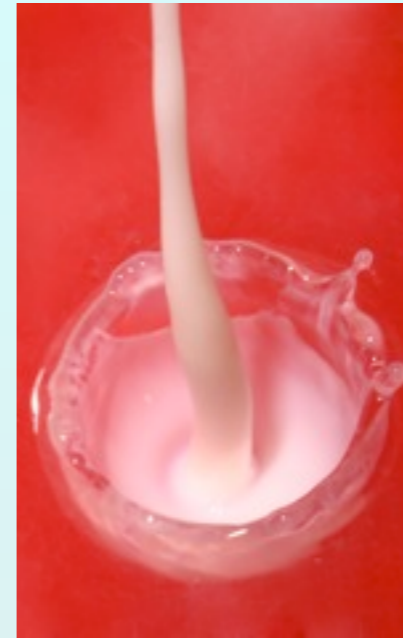
Surprise: the viscosity is very small

Viscosity: inability to transport momentum & sustain a wave

low viscosity → absorbs particles & transports disturbances

Viscosity/entropy near $1/4\pi$ limit from quantum mechanics!

∴ liquid at RHIC is “perfect”



Example: milk.
Liquids with higher viscosities will not splash as high when poured at the same velocity.

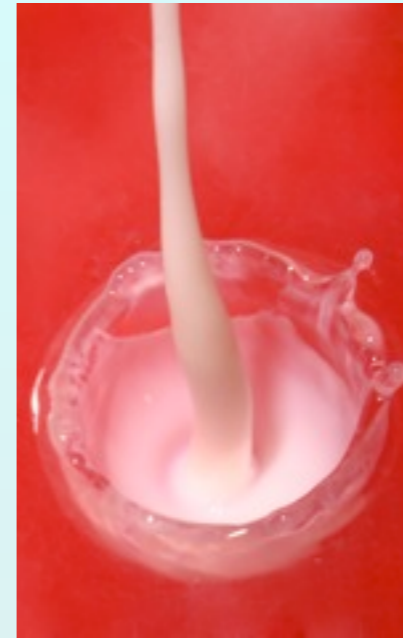
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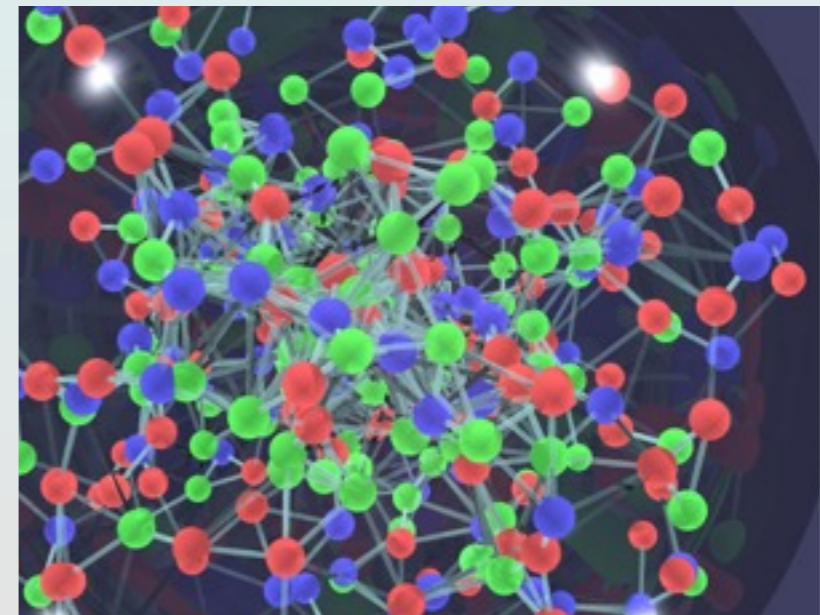


Example: milk.
Liquids with higher viscosities will not splash as high when poured at the same velocity.

Good momentum transport: neighboring fluid elements “talk” to each other

→ QGP is strongly coupled

Explains opacity : q,g collide with “clumps” of gluons, not individuals



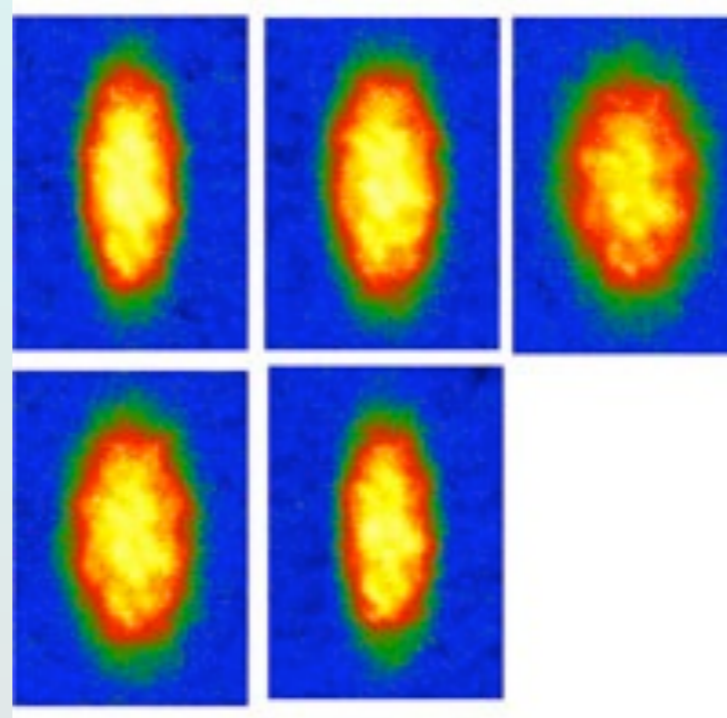
Strongly coupled matter

Quark gluon plasma is like other systems with strong coupling - all flow and exhibit phase transitions



Dusty plasmas & warm, dense plasmas have liquid and even crystalline phases

Cold atoms: coldest matter on earth is like the hottest matter!



Strongly correlated condensed matter liquid crystal phases and superconductors

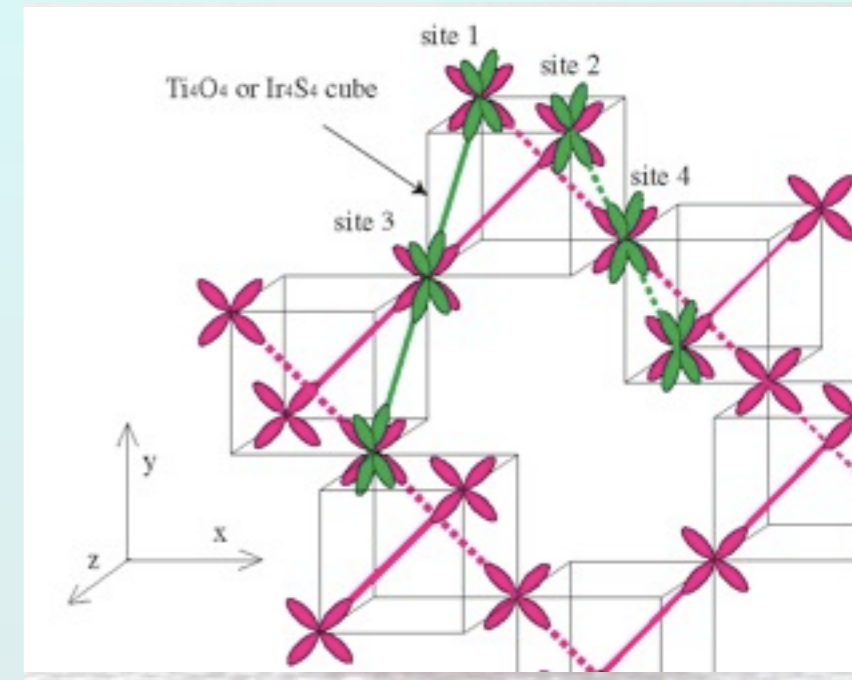
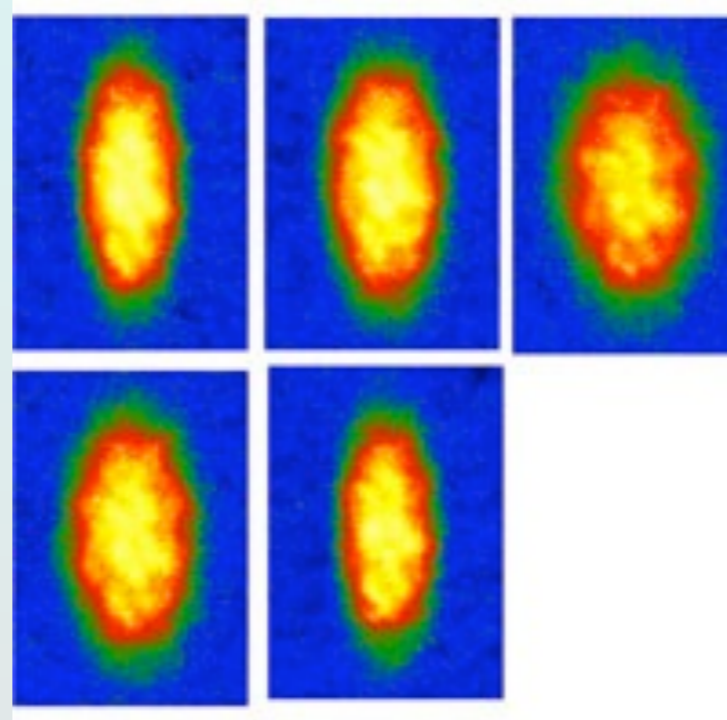
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coldest matter on
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**Strongly correlated
condensed matter
liquid crystal
phases and
superconductors**

In all these cases have a competition

Attractive forces \Leftrightarrow repulsive force or kinetic energy

The attraction wins:

many-body interactions, not pairwise!

Surprise: can use methods from string theory and its duality with black holes (∞ coupling)

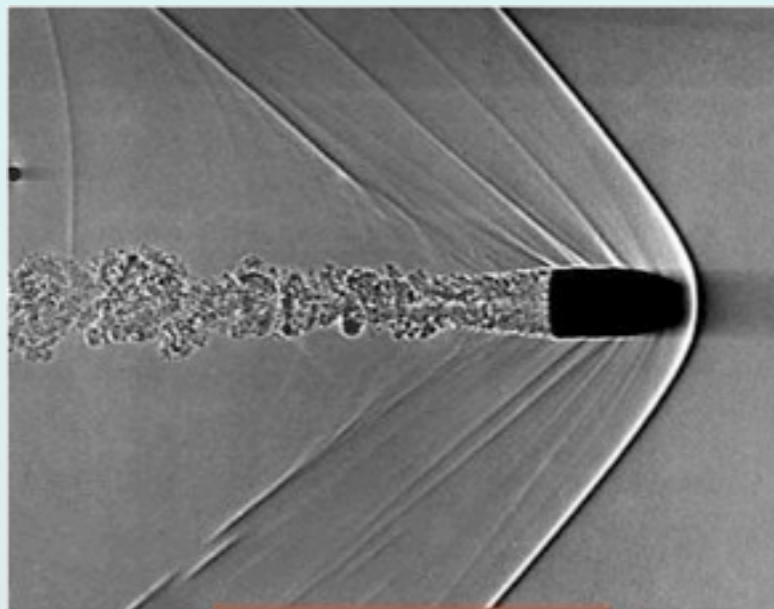
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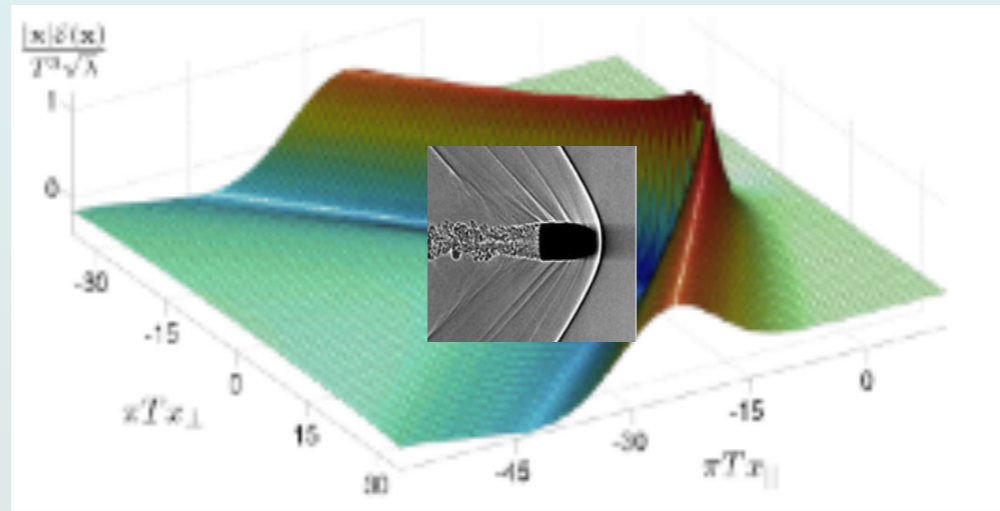
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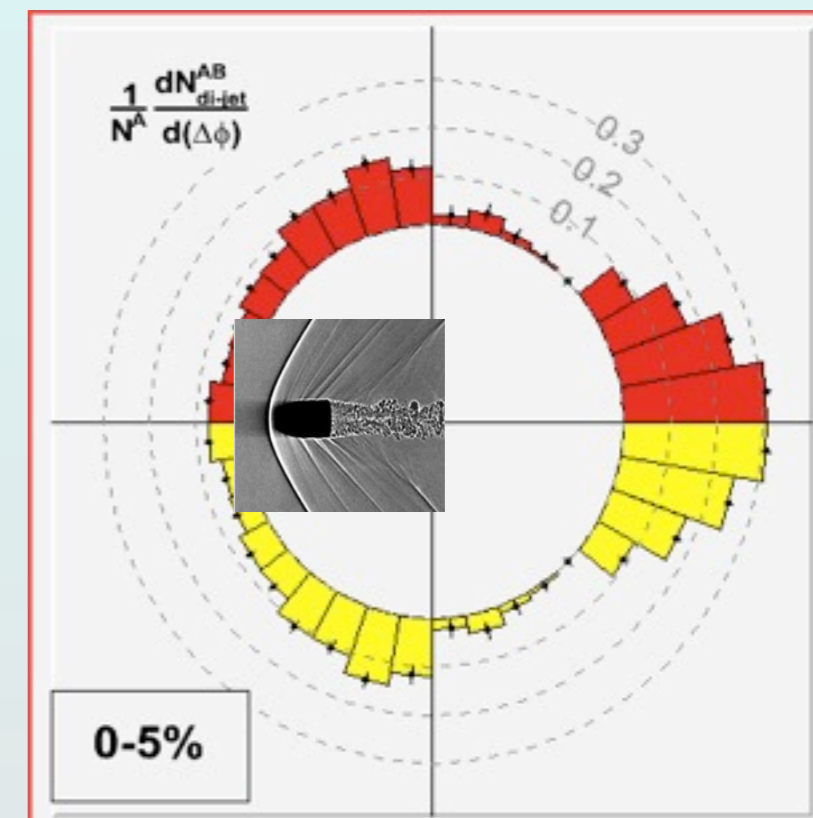


**Shock wave in
quark gluon plasma?**

Chesler & Yaffe, 0706.0368(hep-th)



String theory: yes

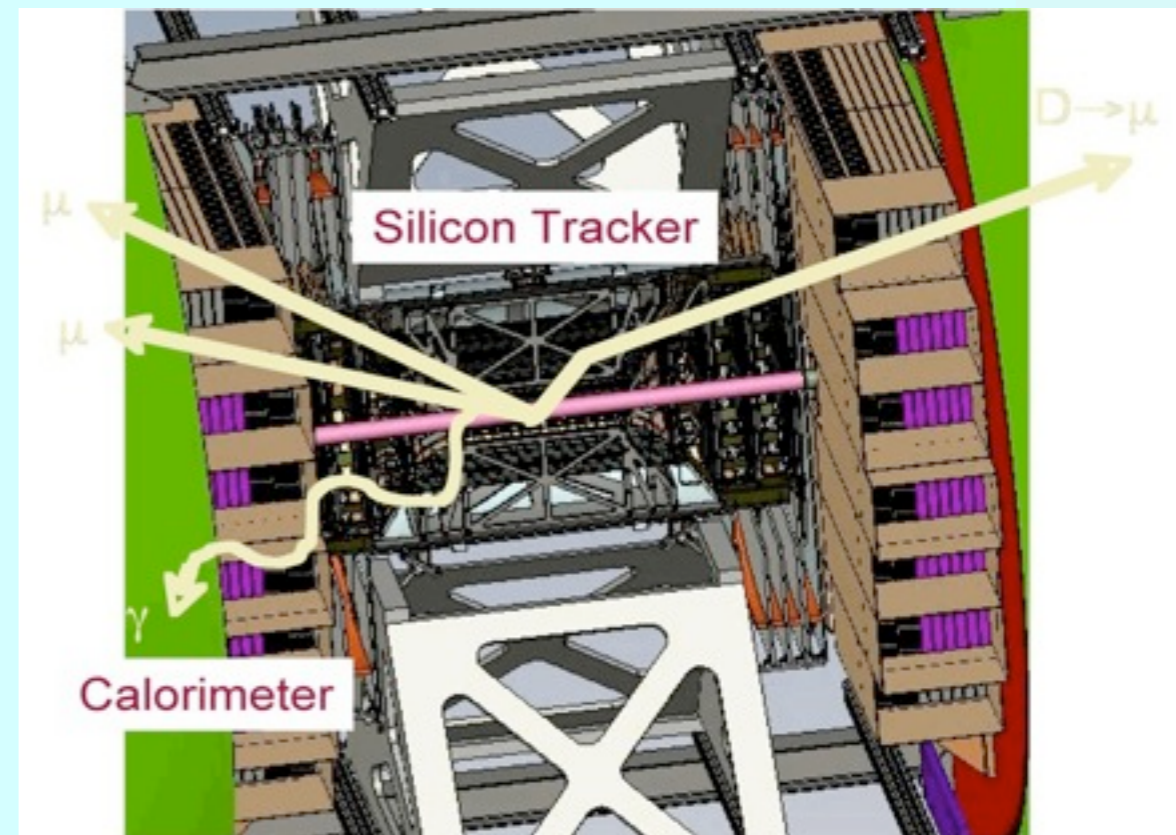
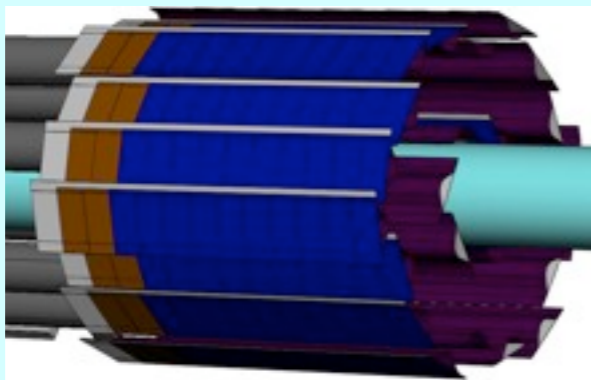


Data too...

To make progress

Probe structure and dynamics of quark gluon plasma to understand its correlations and properties

- Radiation
- Tomography of penetrating probes & plasma's response
- Heavy quark interactions and binding



Accelerator, detector & data acquisition upgrades

- Is there evidence of a critical point in plasma → nucleon phase transition?

Currently a raging debate

- Just *WHAT* is interacting inside this hottest, densest stuff in the universe?

Individual gluons?

Fields rather than particles?

Multi-gluons that continuously split & re-form?

- *Our job: find experimental ways to tell these apart*
We are learning from other fields of physics! ☺

i'm in ur fizx lab



testn ur string therry